REPORT ON THE

CENTER FOR NONLINEAR STUDIES

Introduction

The Center for Nonlinear Studies — CNLS — organizes research related to nonlinear phenomena in physics, mathematics, biology, and engineering. It is part of the Los Alamos National Laboratory located in New Mexico, USA.

The CNLS was formed in October of 1980:

- to identify and study fundamental nonlinear phenomena and promote their use in applied research,
- to stimulate interdisciplinary research and information exchanges inside and outside the Laboratory,
- to provide a focal point for collaboration with academic and other scientific centers of excellence, and
- to disseminate recent developments and introduce young researchers to the subject.

From its inception, the CNLS has served not only as a focal point for nonlinear research at the Laboratory, but also as an internationally recognized resource for the general nonlinear science community. The breadth of research at the Laboratory has offered a fertile environment for the development of CNLS. Three factors have stimulated CNLS growth: the presence of Laboratory experts in many aspects of basic nonlinear science, the existence at Los Alamos of excellent experimental facilities, and the availability of outstanding computational resources.

The mission of the Center is carried out with a very small scientific and administrative staff. The research is organized through a series of themes. These are coordinated by the Executive Committee, formed by the Director, the Deputy Director, the Office Administrator, and a few Laboratory staff members. Within these themes, CNLS hosts around twenty postdoctoral fellows, organizes conferences and workshops, and invites researchers related to its and the Laboratory's interests.

Research Activities

The primary activity of the CNLS is to conduct and support basic scientific research in nonlinear problems, including those that are important to applied research programs. Research in nonlinear science has a long and distinguished history at Los Alamos. One can trace the history from the observations of von Neumann in the late 1940s on the importance of developing digital computers for studying nonlinear fluid dynamics, through the investigations of Fermi, Pasta, and Ulam in the mid 1950's on the unexpected recurrences in nonlinear chains, to the quantitative description by Feigenbaum in the late 1970's of the universality of the period doubling transition to chaos in dissipative dynamical systems.

A number of exciting results have highlighted CNLS research efforts. These include the study of chaotic time-series, solitons, lattice-gas methods for fluid flow, artificial life, non-linear excitations in solid state, HIV epidemiology, turbulence, and the role of noise in transport processes. These research efforts will be discussed in more detail later on in this document.

Conferences and Workshops

The second major activity of the CNLS is to increase the awareness and understanding of recent progress in nonlinear science, both among the Laboratory staff and in the broader scientific community. The continuing interest and excitement engendered by our conferences, workshops, lectures, and colloquia reflect the success of our activities in this area. In May of each year, the CNLS sponsors an international conference that has, in several instances, served to identify the fundamental questions and promising approaches in an emerging area of nonlinear science, and whose proceedings have become widely recognized as seminal works in the respective fields. Notable annual conferences have included "Order and Chaos" (1982), "Cellular Automata" (1983), "Emergent Computation" (1989), "Nonlinear Science: The Next Decade" (1990), and "Nonlinearity in Materials Science" (1992). In addition to its annual conferences, the CNLS typically sponsors ten or more smaller-scale workshops as well as two annual events – the Mark Kac Memorial Lecture Series and the UNM/LANL Lectures in Nonlinear Science – that provide Laboratory staff members and visitors an overview of subjects at the forefront of research in nonlinear science.

Students, Postdoctoral Fellows, and Visitors

The third major activity of the CNLS is the coordination of an active visitor program bringing senior researchers, postdoctoral fellows, and graduate students to Los Alamos for both short- and long-term visits. This activity serves the threefold purposes of enabling the CNLS to identify and explore the widest possible range of nonlinear problems; providing outside researchers with access to the theoretical, computational, and experimental resources of the Laboratory; and fulfilling the educational assets of our mission to disseminate the latest developments in nonlinear science. Each year, over 700 researchers visit Los Alamos under the auspices of the CNLS. In addition, typically 25 or so postdoctoral fellows are in residence at the CNLS and the Center may occasionally host thesis students.

An important component of the visitor program has been the annual appointment of a Stanislaw Ulam Scholar. CNLS Ulam Scholars have included John Holland of Michigan (1987) who catalyzed efforts in genetic algorithms and adaptive dynamical systems; Victor Steinberg of Weizmann Institute (1988) who initiated several successful experimental studies of fluid convection; and Bill Newman of UCLA (1991) who led a research program on nonlinear problems in geophysics and planetary dynamics. In the past, a significant part of the visitor program was funded by the special Institutional Collaborative Research (INCOR) grant, awarded to CNLS by the Office of the President of the University of California, to identify and to support collaborative efforts in nonlinear science between UC campuses and Laboratory staff.

As the field of nonlinear science continues to grow and mature, the focus at the CNLS is on developing, testing, and applying the concepts and techniques emerging in this new scientific discipline. Its long-term goal is to fulfill the promise of nonlinear science to contribute to the understanding of fundamental, unsolved problems in the mathematical, physical, biological, and engineering sciences.

Research

In the next few sections we will highlight the research carried out in CNLS since it was established in 1980. There have been five traditional areas of research: chaos, cellular automata, nonlinear effects in low-dimensional materials, solitons, and pattern formation. Besides these areas there have been efforts in modeling the spread of the HIV virus, on modeling the ocean, and in turbulence. Other areas of research not discussed here include: neural nets, quantum Monte Carlo, soliton propagation in fiber optics, adaptive grids, collapse to an inertial manifold, and others.

Dynamical systems and chaos

Some of the fundamental breakthroughs in the area of dynamical systems were achieved at Los Alamos National Laboratory. In part, the establishment of the Center for Nonlinear Studies in 1980 was a consequence of the developments that stemmed from these breakthroughs.

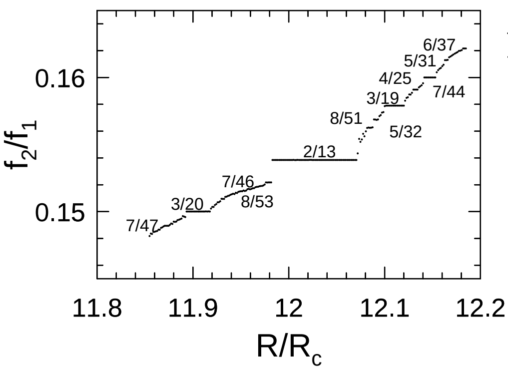
In the late 1970's, Mitchell Feigenbaum (T-Division) — building upon earlier work by Stan Ulam, John von Neumann, Mark Kac, Nick Metropolis, Paul Stein, and Stephan Smale [1] — made a key discovery connecting the qualitative and quantitative scaling behavior of a simple mathematical equation. Central to the work was the realization of the *universality* of chaos; Feigenbaum's theoretical work predicted that under certain circumstances, much of the detailed structure of chaotic behavior, particularly during onset, is independent of the specific system being studied [2]. These predictions have since been confirmed experimentally in a convincingly diverse range of real systems — including hydrodynamics, optics, acoustics, population dynamics, and nonlinear electrical circuits and semiconductors.

At CNLS, Feigenbaum's work sparked a series of research activities in the area of dynamical systems. Algorithms were developed to determine fractal dimensions and predict time-series; the approach to quasi-periodic behavior was studied analytically and experimentally, and higher dimenional systems where studied from the dynamical systems perspective.

Doyne Farmer, a CNLS Oppenheimer Fellow, helped define many of the fractal dimension algorithms used in the early analysis of laboratory experiments [4]. With Erica Jen, another CNLS Postdoctoral Fellow, they analyzed the experimental data of a fluid flow (from Harry Swinney's group at the University of Texas at Austin). They showed that the data could be understood in terms of low-dimensional chaotic attractors. This was the first convincing proof that hydrodynamic flows could be modeled by simple dynamical systems. It has led to a large area of research and to the application of fractal dimension algorithms to many different systems. papers that cite Doyne

The work of Farmer and collaborators took the perspective that the only information one could measure from a chaotic dynamical systems was the time series of an observable. The time series should be the basis for further predictions and characterization of the system. This lead Farmer and Sidorowich to development of algorithms for predicting the future behavior of chaotic systems [5]. This paper has been the basis of many algorithms and led to the establishment of an entire industry that attempts to predict the stock market. Farmer himself established Prediction Inc. and hired several of the post doctoral fellows from CNLS to work with him. When analysing a time-series a basic question is to what extent is the system predictable. Theiler, then a postdoctoral fellow at CNLS developed the method of surrogate data to study time-series [6]. By shuffling the data points in a way that preserves certain global features of the time-series, one can check the efficacy of a proposed algorithm.

The route to chaos often starts with periodic behavior. While supported by CNLS, Feigenbaum collaborated with Kadanoff and Shenker to give a renormalization group analysis of the quasiperiodic route to chaos [7]. The experimental implications of this work were investigated by Robert Ecke. Interacting with a wide range of CNLS visitors and postdoctoral fellows, he led a program that



the most precise measurements of the quasiperiodic route to chaos [15, 16]. The first realistic reconstruction of the dynamical scaling function of Feigenbaum for the quasiperiodic attractor at the golden mean rotation number was obtained in this experimental program using novel analysis techniques [17].

The analysis of experimental time-series has prompted the study of the effects of noise in chaotic systems. Hasslacher and Feigenbaum pioneered the use of path integrals in the study of dynamical systems [18]. The techniques of field-theory have been adapted to the study of dynamical systems in the area of cycle expansions, leading to the first general formula for the computation of the Lyapunov exponent for a product of random matrices [19].

It is still not clear if the techniques of low-dimensional dynamical systems can be used in the study of high-dimensional systems, such as fluid flows and other systems described by partial differential equations. When discretized, partial differential equations led to sets of coupled maps. Kaneko studied them extensively [21, 22]. This led to very interesting result on the convergence of simulations [20].

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Cellular automata

The development of lattice gas techniques for the simulation of the Navier-Stokes equation provides a remarkable example of the long-term and often unexpected process by which basic research contributes to practical applications, and of the essential interplay in this process among different disciplines. The lattice gas techniques are based on simple mathematical systems known as “cellular automata” originally invented by von Neumann and Ulam (then at the Laboratory) in the 1950s as “toy” models of biological reproduction. After several decades of relative quiescence, the topic of cellular automata experienced a dramatic resurgence of interest. In the early 1980s, Stephen Wolfram, then at the Institute for Advanced Studies at Princeton and a frequent CNLS visitor, made several advances in our understanding of cellular automata. Adopting the viewpoint that cellular automata represent a general class of novel discrete mathematical systems, Wolfram performed extensive computer simulations to identify the fundamental qualitative features of these systems in their simplest form as defined on one-dimensional lattices. Some of Wolfram’s earliest simulation studies of one-dimensional binary site-valued, nearest-neighbor cellular automata were implemented on CNLS computers, and described in his Fall 1983 article in *Los Alamos Science*. In March 1983 the CNLS sponsored a conference “Cellular Automata”—with J.D. Farmer (then a CNLS postdoctoral fellow), T. Toffoli (MIT), and Wolfram as co-organizers—the proceedings of which were published by *Physica D* and are viewed today as a seminal text in the subject.

On the basis of the mathematical and computational studies of cellular automata carried out during the early and mid 1980s (many under the auspices of the CNLS), a provocative set of ideas emerged within the scientific community.

The first set of ideas is that cellular automata represent prototypical spatially extended dynamical systems, important both theoretically and practically as systems defined to be fundamentally *discrete*, rather than continuous, in space, time, and state values. Simple in construction but capable of generating complex behavior, a cellular automaton’s evolution in time can be viewed as the implementation of an inherently parallel form of discretized computation.

The second set of ideas is that cellular automata provide mathematical models for the type of complex behavior generated by physical and biological systems consisting of a large number of simple, uniform, locally interacting components. For such behavior, cellular automata-based algorithms can provide solutions that differ in microscopic detail from, but exhibit qualitative and quantitative macroscopic agreement with, conventional solutions obtained by partial differential equations.

As an outgrowth of the above ideas, research in cellular automata has proceeded at CNLS, at the Laboratory, and throughout the scientific community as a whole, in a variety of interrelated directions.

Perhaps the most noteworthy application of cellular automata has been the development of cellular automata-based techniques for the study of fluid flows and related physical phenomena. In the mid 1980s, Brosl Hasslacher (T-8) initiated CNLS-sponsored collaborations with Uriel Frisch and Yves Pomeau (CEN-Saclay) with the goal of using cellular automata to design novel parallel-processing algorithms, subsequently to be called "lattice gases," for the simulation of the motion of fluid particles. This in turn led to the development of a code for the flow through porus media, by S. Chen (then a CNLS sponsored Oppenheimer postdoctoral fellow) and collaborators. This code won the Laboratory an R&D 100 award. Lattice gas models have also served as the basis for studying active flows that display Turing instabilities.

Another application of cellular automata has been in the development of the field of artificial life. The goal in artificial life is to create within the computer the processes of biological systems without necessarily reproducing its methods. It creates a synthetic biology in the hopes that it will lead to better understanding of biology. The field has been promoted by Christoffer Langton. While a postdoctoral fellow with CNLS and with its sponsorship, he organized the first Artificial Life conference in September of 1987.

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Nonlinearities in material science

It has been recognized from early days that strongly nonlinear effects on ground states and excitations are particularly apparent in reduced dimensions. Consequently, the explosion of interest in chaos and coherence from the late 1970s onwards lead to focuses on low- dimensional (zero, one, two) electronic, magnetic, optical and structural materials. The nonlinearity typically arises from coupling and slaving of fields (spin, charge, lattice) and topological constraints, resulting in a rich variety of nonlinear patterns — solitons, polarons, excitions, breathers, vortices, dislocations and so on. When combined with considerations such as dimensional anisotropy, disorder, noise and lattice discreteness, the nonlinearity produces striking phenomena of spatio-temporal complexity dominating physical mechanisms for thermodynamics and response functions.

From its inception, CNLS has occupied a prominent position in this area of condensed matter physics and materials science — developing modeling frameworks (using a synergism of analysis and large-scale computation), and coupling strongly to synthesis and characterization programs at Los Alamos and elsewhere — designing experiments and interpreting them has been a challenge in itself. Very strong contributions have been made at CNLS to many of these materials science fields, including displacive structural phase transitions; quasi-one- and two-dimensional magnetic (sine-Gordon and nonlinear Schrödinger models and generalizations); Josephson transmission lines (sine-Gordon-like models); self-focusing in molecular crystals (nonlinear-Schrödinger-like models); organic and inorganic charge- and spin-density-wave materials, especially conjugated polymers, charge-transfer-salts and ionic conductors (nonlinear field theories, coupled nonlinear-Schrödinger-like models); nonlinear transport and stick-slip.

Innovative multidisciplinary Workshops and Conferences organized by CNLS (often jointly with CMS or other organizations) included *Nonlinearity in Condensed Matter* (1986); *Competing Interactions and Microstructures* (1988); *Nonlinearity in Materials Science* (1992); *Nonlinearity with Disorder* (1991); *Quantum Complexity in Mesoscopic Systems* (1994).

These Workshops and the associated programs of students, postdocs and visitors established the actual directions of the field of complexity in materials science at Los Alamos — an appreciation that multiple spatial and related temporal scales are intrinsic in many real materials and that this multiscale complexity, if it can be controlled, may offer new strategies for existing and future technologies. In the 1990s these notions have become central leitmotifs for many R&D programs at Los Alamos (and of course elsewhere): successful programs which are largely undertaken in experimental and theoretical groups around the Laboratory with CNLS playing a gluing, interprogram role through seminar series, students, postdocs and visitors. These programs and thrusts include: Flux flow in layered superconductors (STC/T), Polymer light-emitting diodes (MST/T), Organic self- assembly (CST/MST/T), Thinfilms and interfaces (MST/T), Organic superconductors in high magnetic fields (HMFL/MST/T), Charge-localization and metal-insulator transitions in transition-metal oxides (LANSCE/MST/T), Mixed-Valence Salts (CST/T), Ultrafast spectroscopy (CST/MST/T), Polymers and complex fluids (MST/T), Solid-solid phase transformations (MST/T), and Nonequilibrium science (X/T).

New Materials Projects under development at the Laboratory in which CNLS is playing distinctive roles include: integrated electronic-structural characterization; (stochastic) assessment and prediction; soft-condensed matter and biomimetic materials; and complex (multiscale) adaptive matter. These all represent the unifying heritage of nonlinearity in modern electronic and structural materials that there is (space-time) complexity, with functionality at many scales. Understanding, controlling, and using this multiscale complexity demands understanding the microscopic origins of mesoscale complexity, measuring the mesoscales, and relating the measures to macroscopic functionalities. This introduces fundamental nonlinear, nonequilibrium, nonadiabatic, disordered, discrete glassy phenomena which have been little understood to date and represent striking challenges to the CNLS. This year's CNLS program engages these challenges through specific Lab/external focuses on "Multiscale hierarchical materials" microstructure and evolution, "Complex organic and inorganic electronic materials," "Dynamic friction and fracture," and "Nonequilibrium phases and transformations."

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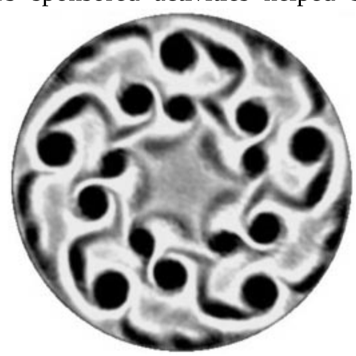
Pattern formation

The formation of patterns, the selection of the length scale for the patterns, and their role in physical phenomena make the study of this area one of the most exciting in nonlinear science. Although this was not a topic of major CNLS activity during its first decade 1980-1990, recently more attention has been focused on pattern formation. On the experimental front this was directly attributable to the appointment in 1987 of Victor Steinberg of the Weizmann Institute of Science as the CNLS Ulam Scholar. His activities in CNLS and in the Condensed Matter and Thermal Physics Group nucleated experiments using optical shadowgraph techniques to image patterns and vortex structures in rotating Rayleigh-Bénard convection. In addition, the 1987 CNLS Annual Conference "Advances in Fluid Turbulence" organized with the help of Steinberg, served to stimulate Laboratory research in spatially-extended nonlinear systems. Some early accomplishments were the first observations of vortex structures in a convection flow contained in a closed rotating cylinder and the experimental discovery of the side-wall traveling-wave which explained previous anomalous heat transport measurements. Subsequent recent investigations of the side-wall mode demonstrated the first experimental system that is well described by the cubic complex Ginzburg-Landau equation.

Another set of experimental investigations were begun in 1988 on the Küppers-Lortz transition in rotating convection in collaboration with Guenter Ahlers (Department of Physics, UC Santa Barbara) and supported by the CNLS/UC INOCR Program in Nonlinear Science. These CNLS sponsored activities helped build

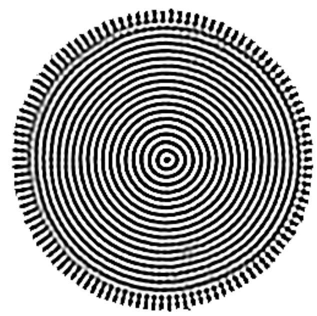


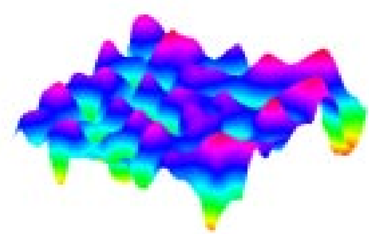
ongoing experimental research on rotating and non-rotating convection in compressed gases. This work stimulated theoretical efforts at Cal Tech and at UC Berkeley and has become one of the exciting new research topics in pattern formation. Highlights include the first study of the onset of the novel spiral-defect-chaos state in large-aspect-ratio Rayleigh-Bénard convection, the chiral-symmetry breaking of rotation on spiral structures, and the first quantitative study of the effects of rotation on pattern-forming instabilities. The formation and dynamics of convective structures in Rayleigh-Bénard convection continues to be an active area of CNLS research.

Using the ideas developed within

CNLS on pattern formation, an important Laboratory problem was attacked. A researcher in Nuclear Materials Technology Division had done a difficult experiment on the dissolution of titanium by liquid plutonium and had apparently observed patterns formed in the dissolution process. Could these patterns result from some known process and could simple experiments elucidate this behavior? Using an analogous system of crystalline salts dissolved in water, CNLS researchers quickly found that patterns indeed form in the unstable dissolution of a material, *i.e.*, when the dissolved material is gravitationally unstable with respect to the solvent. Although turbulent boundary layers are important in that problem, the growth of surface patterns was measured to be a linear stability problem. The abilities developed partly in CNLS were crucial to the rapid understanding and characterization of this Lab problem.

Another area of active exploration has been the novel patterns and spiral-wave dynamics of reaction-diffusion systems. First proposed theoretically by Turing in 1952, spatial patterns in reaction diffusion systems were only recently observed. Novel experiments at UT Austin were suggested by numerical work of CNLS researchers, which in turn led to predictions of unusual "self-replicating" spots in these reaction-diffusion systems. Subsequent experiments indeed revealed such spots which have an uncanny resemblance to cell nucleation and division. Other work within CNLS made quantitative inroads into the understanding of front propagation in spiral-waves. Important work continues in these areas including extensions of concepts of pattern formation in reaction-diffusion to other biologically relevant systems such as calcium waves in cell processes.





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Turbulence

Turbulence, “the last unsolved problem in classical statistical mechanics” (Feynman), has been with us over 100 years since Reynolds found the laminar-turbulent transition in 1883. During this entire century, turbulence has been a great challenge for both theory and computation. For practical applications, people use idealized, highly parameterized turbulent modeling with arbitrary assumptions. Although the mechanisms of turbulence usually are poorly represented in these models, and the values of the model parameters must be obtained empirically, such models are widely used and have great impact in diverse applied problems, such as engine and aerofoil design and global circulation models. On the other hand, theoreticians study turbulence as a stochastic dynamic system and try to relate the basic physical phenomena in turbulent flows to the underlying equations of motion. One of the hopes of this fundamental research is that it will provide insights into how to improve turbulence modeling.

The difficulties in physical understanding and modeling of fluid turbulence arise from fundamental dynamical properties: strong nonlinearity; the simultaneous presence and interaction of a huge number of degrees of freedom, comprising a wide range of spatial scales; and marked departure from absolute statistical equilibrium. More than 10^{18} degrees of freedom can be excited in turbulent flows typical of atmospheric phenomena. This makes full computer simulation of the flow impossible.

In the last five years, a turbulence research group has been formed in the Center for Nonlinear Studies to study important issues in the fundamentals of fluid turbulence. The achievements include the following subjects:

1. A novel theoretical approach, called mapping closure, has been originated at Los Alamos National Laboratory. The new and key feature of the mapping closure is direct handling of PDFs in physical space, rather than the use of moments in wave-vector space and perturbation expansions as in traditional statistical theories of turbulence. The basic idea in the mapping closure is to approximate an actual turbulent field by tractable nonlinear transformations, or mappings, of a Gaussian reference field. The method has been applied successfully to the relaxation of an initially non-Gaussian scalar field obeying the heat equation, the evolution of Burgers turbulence, and the statistics of a temperature field that suffers both random advection and molecular diffusion.

2. Direct numerical simulation has become a powerful tool for the study of turbulence. Recent improvements in computer memory and speed, and especially the availability of well-integrated massively parallel machines, have made computer simulation a necessary supplement to laboratory experiments. Concurrently, faster and more powerful graphics pro-

cessing has become feasible. At present, laboratory experiments can reach higher Reynolds numbers (more degrees of freedom) than simulations, but simulations offer more precise control of parameters and more complete datasets. The latter are an impetus toward the development of new interactive visualization techniques to aid in the identification and understanding of flow structures.

High-resolution direct numerical simulation data for three-dimensional Navier-Stokes turbulence in a periodic box with 512^3 grid points (the largest simulation in the world for the fluid tubrulence problem) have been generated for studying the scaling properties of the velocity structure functions. It is found that the inertial-range statistics, both the scalings and the PDFs, are independent of the dissipation mechanism, while the near-dissipation-range fluctuations show significant structural differences. Nevertheless, the relative scalings expressing the dependence of the moments at different orders are universal, and show unambiguous departure from the Kolmogorov 1941 description, including the 2/3 law for the kinetic energy.

3. The advection of a passive scalar field by a rapidly decorrelating random velocity field with powerlaw scaling is computed by simulations in a cyclic square at resolutions of 4096^2 and 8192^2 points. Various statistics of the the scalar field, including inertial-range scaling exponents, are analyzed and compared with theoretical predictions from a linear ansatz. This research has stimulated heated debates for this subject.

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HIV modeling

In 1987 many of the CNLS affiliates were most concerned about understanding the future of the HIV epidemic and worked with Stirling Colgate in T division to start a project modeling the transmission of HIV. The initial investigators included Mac Hyman, Ann Stanley (CNLS PD), Scott Layne (CNLS PD), Alan Perelson, Stirling Colgate, Cliff Qualls, Bill Beyer, Jia Li (CNLS PD), and Gerry Meyer's HIV database team.

In the late 1980s, we developed one of the first biased mixing models for the spread of the HIV infection based on the risk behavior of the population. Our deterministic model for a homosexual community distributes the population according to the number of sexual partners per year and keeps track of time since infection for infected population and time since diagnosis for AIDS cases. In our model, susceptible persons are infected through contacts with infected persons, and infected persons develop clinical AIDS [such as Kaposis sarcoma (KS) or opportunistic infections such pneumocystis pneumonia (PCP)] at a rate that depends on the length of time since the HIV infection. We used the model to demonstrate that random partner choice predicts a dramatically different from a model that assumes strong bias of "like prefers like," and that variations in infectivity over the course of infection can strongly affect the spread of the epidemic. We used our model results to argue that the cubic growth of the number of AIDS cases in the epidemic results from this biased mixing, and thus data on mixing patterns as well as on infectivity is crucial to understanding the spread of the epidemic. Jim Wiley at the UC Berkeley Survey Research Center used these results to help design of a number of sexual behavior studies in which individuals were asked about their partners characteristics for the first time.

Next we entered a major simulation effort with WHO, USAID, the CDC and the State Department to extended our model for the prediction and control of the HIV epidemic in third world countries. Ann Stanley derived the most comprehensive equations ever constructed to model the spread of an infectious disease. The model was developed in close collaboration with Steve Seitz (University of Illinois) to implement this model in a user-friendly computer model, and Peter Way (US Census Bureau) to ensure that the demographic part of the model was realistic. The model has now been used by epidemiologists in a number of countries, including Uganda and Thailand, to predict spread and help design intervention strategies. Results from an early version of the model convinced the president of Uganda that condoms should be legalized and encouraged, a move which has contributed enormously to a decrease in HIV spread in that country. Sensitivity studies on the model showed that the AIDS epidemic is sensitive to both the biological aspects of

HIV infection and the human behaviors that spread HIV.

Following the large-scale prediction and control project, in the mid 1990s we (Jia Li, Mac Hyman and Ann Stanley) turned to theoretical studies on how control measures can impact the course of an epidemic. We usually had AIDS as a potential application, but we began to work on more general classes of infectious diseases. Some of the questions we worked on include how strategies, such as isolating the infected population, will impact the course of the epidemic. We also looked at sensitivity questions such as how two different transmission models can match the infection incidence data, have the same reproductive numbers and asymptotic steady states, but respond very differently to control measures, such as contact tracing. We also derived new relationships to help health officials at the Centers for Disease Control to estimate the size of the infected population from data reporting the number of confirmed cases of a disease. The improved error estimates and formulae were obtained by solving a Fredholm integral equation of the first kind.

We continue our research in modeling infectious diseases and working with the Centers for Disease Control. For example, last summer Mac Hyman joined Herb Hethcote (U. Iowa) to teach a two-day short course on Epidemiology Modeling in Atlanta. The course is co-sponsored by the Centers for Disease Control and the Mathematical Association of America.

Ocean modeling

Understanding the processes that control the Earth's climate and predicting future changes in climate due to natural and man-made causes will require computer models of the climate system that are more comprehensive and realistic than those we now have. Such models, known as general circulation models or global climate models, describe the time-evolving circulation and thermodynamics of the atmosphere and oceans, the two main components of the climate system. One of the main difficulties in developing better models is the limited computational capacity of present-day supercomputers. To overcome this limitation one can use asymptotic methods developed first in the geometrical theory of diffraction [7].

In this project the problem of finding Hamilton's principle for the basic quasi-geostrophic model of atmospheric and oceanic dynamics was solved [6] and the Euler-Poincaré formulation of ideal continuum dynamics was discovered by Holm (LANL) Marsden (Caltech) and Ratiu (UCSC) [91].

The theory of Euler-Poincaré (EP) equations with advected parameters and the methods of Hamilton's principle asymptotics and averaged Lagrangians, led to a new class of models for ideal incompressible fluids in three dimensions, including stratification and rotation for global fluid dynamics applications. In these models, the amplitude of the rapid fluctuations introduces a length scale below which wave activity is filtered by both linear and nonlinear dispersion. This filtering enhances the stability and regularity of the new fluid models without compromising either their large scale behavior, or their conservation laws. These models also describe geodesic motion on the volume-preserving diffeomorphism group for a special metric that includes the fluid velocity. These models are expected to be useful for numerically simulating large-scale weather patterns and global wind-driven ocean circulation over long times.

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Lattice-Boltzmann

The Lattice Boltzmann method is a recently developed computational scheme that has the capability to model a wide variety fluid flows. Its distinct advantages over traditional numerical methods include the efficiency of local operations and parallel logic. As a result, the Lattice Boltzmann method is ideally suited for implementation on massively parallel computers, including the Connection Machine-5. Moreover, since it deals with fluid dynamics from the microscopic, kinetic level, it is extremely flexible and can simulate phenomena for which traditional methods may be overly complicated or may not even exist.

The macroscopic or hydrodynamic (e.g. Navier-Stokes, Euler) level description of fluids results from a coarse-graining of the underlying, microscopic particle dynamics. Traditional kinetic theory makes this micro-to-macro connection through the (coarse-grained) particle velocity distribution function whose evolution is governed by the Boltzmann equation. This integro-differential equation is composed of two parts representing the free streaming and collision of particles. The starting point of the Lattice Boltzmann method is a space-time discretized form of this equation. While this may be viewed as a finite difference scheme, it retains the simple, physical picture which originated with lattice gas models where particle streaming and collision are explicitly computed. The streaming and collision terms may be selected to model a wide variety of physical systems.

With Lattice Boltzmann codes, our group at CNLS and T-13 has studied a variety flows. Using a three-dimensional Lattice Boltzmann model, we recently completed several benchmark tests which demonstrate that the Lattice Boltzmann method is about 2.5 times faster than a pseudo-spectral code for turbulent fluid flows on uniform meshes. An important property of the Lattice Boltzmann method is that simulations of flows in both simple and complex geometries have the same speeds and efficiencies, whereas all other methods, including the spectral method, are unable to model complicated geometries efficiently. Recently, our group has constructed and tested models for the simulation of thermohydrodynamic phenomena, chemical pattern formation, non-Newtonian fluids, and multiphase fluids including effects of immiscibility, surface tension and density variation. Our simulations agree well with documented results.

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Activities

In the next few sections we will highlight some of the activities of the CNLS. They include the Ulam scholars the Center has hosted, the Mark Kac lectures it has organized, the annual conferences it has held, and the staff responsible for the operation of the center. For each year, we only list the annual conference among the ten or so conferences that CNLS hosts. Some of the more recent ones are listed on our web site. There is also a list of the Postdoctoral fellows from CNLS and their current positions; many have taken a technical staff position at the Laboratory.

Stanislaw Ulam Visiting Scholar

The Stanislaw M. Ulam Distinguished Scholar is an annual award which enables a noted scientist to spend a year carrying out research at the Center for Nonlinear Studies at Los Alamos. The Ulam Scholarship honors the memory of the brilliant Polish-American mathematician Stan Ulam, who was among the founders of what has now become "nonlinear science." A number of the Ulam Scholars from the 1985 until the present have made significant contributions to Laboratory efforts in nonlinear science and many continue to collaborate with researchers in the technical divisions. The Ulam scholars and their areas of interest have been:

- **1985 Professor James D. Murray** Director of the Center for Mathematical Biology, Oxford University, UK.

  Senior Research Fellow at Oxford University; Research in mathematics and mathematical biology; rabies model and morphogenisis.

- **1986 Professor Adrian Patrascioiu** Department of Physics, University of Arizona.

  Elementary particle and quantum field theory; research on the ergodic theorem of statistical mechanics and the Fermi-Pasta-Ulam problem.

- **1987 Professor John H. Holland** Department of Computer Science & Engineering, University of Michigan.

  Computer science, adaptive dynamical systems, both natural and artificial.

- **1988 Professor Victor Steinberg** Department of Nuclear Physics, Weizmann Institute of Science, Israel.

  Experimentalist working on hydrodynamic instabilities, pattern formation, and transition to turbulence; helped start program in rotating thermal convection; co-organizer of 1988 CNLS Annual Conference "Advances in Fluid Turbulence.".

- **1989 Dr. Kunihiko Kaneko** Institute of Physics, University of Tokyo, Japan.

  Pattern formation and selection, models for open fluid flow and turbulence, statistical mechanics of cellular automata, "coupled map lattice" model for studying spatio-temporal chaos and the approach to turbulence in spatially extended systems.

- **1990 Professor Stephen R. Wiggins** Department of Applied Mechanics, California Institute of Technology.

Nonlinear dynamics, chaotic phenomena, local and global bifurcation theory, control theory, dynamics of continous media, and nonlinear optics. Research on chaotic advection in transport problems.

- **1991 Professor William I. Newman** Department of Earth and Space Sciences, University of California.

  Broad and interdisciplinary interests, ranging from rigorous applied mathematics to applied magnetohydrodynamics in connection with stellar magnetic field generation.

- **1992a Professor Philip Rosenau** Department of Mechanical Engineering, Technion Institute.

  He has made important contributions in fluid dynamics, plasma physics, continuum mechanics, and astrophysics/space science.

- **1992b Professor Serge Aubry**, Laboratoire Leon Brillouin, Saclay, France;

  Commensurate solid-state materials and excitations in metal-insulator and superconductor-insulator systems. Anti-integrable limit which promises to be another breakthrough in condensed matter physics. Winner of both the Bronze and Silver Medals of the French CNRS and the Langevin Prize of the French Physical Society.

- **1993 Professor Lee Segel**, Department of Mathematics, Wiezmann Institute of Science, Israel.

  Theoretical immunology and applied mathematics.

- **1994 Thomas Manteuffel**, Applied Mathematics Department, University of Colorado at Boulder.

  Iterative methods for solving large sparse linear systems, multigrid methods for solving partial differential equations, and numerical solution of mathematical models of the transport of neutral and charged particles.

- **1995 Yannis G. Kevrekidis**, Chemical Engineering, Princeton University.

  Dynamics behavior of reaction and transport processes, interfacial instabilities and transitional flows, the dynamics of chemical reactors, and nonlinear system identification and control. Recepient of the Allan P. Colburn Award and Presidential Young Investigator Award.

- **1996 David Sherrington**, Physics, Oxford University.

  Complexity due to disorder and frustration. Spin-glasses, randomly pinned charge-density waves, hard optimization problems, neural networks.

- **1997 David Pines**, Physics, University of Illinois at Urbana-Champaign.

  Condensed matter physics and theoretical astrophysics. High-temperature superconductivity. Member of the National Academy of Sciences.

- **1998 Ciprian Ilie Foias**, Mathematics, Indiana University at Bloomington,

  Operator theory, interpolation theory, rigorous estimates of for the Navier-Stokes equation. Recipient of the Norbert Wiener Prize in Applied Mathematics, member of the American Association for the Advancement of Science.

Mark Kac Memorial Lectures

To honor the founding Chairman of the CNLS External Advisory Committee, the Mark Kac Annual Memorial Lecture Series was established in 1985 as a fitting and continuing tribute to his lifelong commitment, not only to the pursuit of scientific research of the highest quality, but also to the broad dissemination of the results of this research.

- **1986 Joel L. Lebowitz** Dept. Physics, Rutgers Univ.

  "*From Determinism to Chance and Back Again: Microscopic and Macroscopic Time Evolutions*"

- **1987 Joseph Ford** Dept. of Physics, Georgia Inst. of Tech.

  "*The Fermi-Pasta-Ulam Problem: Past Becomes the Future: Paradox Becomes Discovery*"

  "*What is Chaos, That We Should Be Mindful of It*?"

  "*Chaos: Solving the Unsolvable; Predicting the Unpredictable!*"

- **1988 Jerry P. Gollub** Dept. of Physics, Harverford College.

  "*Nonlinear Dynamics of Interacting Waves: Symmetry and Multiple Bifurcations*"

  "*Transport Processes and Flow Patterns in Convecting Fluids*"

  "*Pattern Formation at the Liquid/Solid Interface*"

- **1989 Philip Holmes** Dept. of Applied Math., Cornell Univ.

  "*Poincare, Celestial Mechanics, Dynamical Systems Theory and Chaos*"

  "*Can Dynamical Systems Approach Turbulence?*"

- **1990 Alan Newell** Dept. of Applied Mathematics, Univ. of Arizona.

  "*Nonlinear Optics*"

- **1991 Harry Swinney** Dept. of Physics, Univ. of Texas, Austin

  "*Observations of Chaos and Pattern Formation: Laboratory Model of the Great Red Spot of Jupiter*"

  "*Observations of Chaos and Pattern Formation: Chemical Pinwheels, Spirals and Crystals*"

  "*Observations of Chaos and Pattern Formation: Instabilities and Turbulence in Flow between Concentric Rotating Cylinders*"

- **1992 Nancy Kopell** Dept. of Biology, Boston Univ.

  "*Rhythms and Clues: Mathware for Wetware: Chains of Oscillators and Undulatory Swimming*"

  "*Rhythms and Clues, Geometry and Biophysics: Which Differences Make a Difference?*"

  "*A Geometric View of Singular Perturbations: Case Studies*"

- **1993 Israel M. Gelfand** Rutgers University

  "Some ideas on mathematics and biology"

  "Part I: Some special questions of spectral theory and integrable systems"

  "Part II: Some special questions of spectral theory and integrable systems"

- **1994 Pierre C. Hohenberg.** AT&T Bell Laboratories.

  "Topics in nonequilibrium pattern formation: spatiotemporal chaos"

  "Topics in nonequilibrium pattern formation: flutuations and noise in pattern forming systems"

  "Topics in nonequilibrium pattern formation: nonlinear waves and coherent structures in the complex Ginzburg-Landau equation in one dimension"

- **1995 Joseph B. Keller** Stanford University.

  "Semiclassical mechanics"

  "Wave propagation"

  "Nonreflecting boundary conditions"

- **1996 Edward Spiegel.** Columbia University.

  "Solitary waves in the natural sciences. Patterns of propagating pulses"

  "Solitary waves in the natural sciences. Waves of solar activity"

  "Solitary waves in the natural sciences. Bifurcation of spicies"

- **1997** There were no Kac Lectures that year.

Annual Conference

The Center for Nonlinear Studies sponsors an annual conference devoted to a topic in nonlinear science, often in conjunction with an ongoing research theme being developed at the Laboratory. This conference is funded by the US Department of Energy, Office of Basic Energy Science, Division of Applied and Computational Mathematics. Many of the conferences have been seminal contributions to the field of nonlinear science.

- **Nonlinear Problems: Present and Future** 3/2-6/81; Alan Bishop, David Campbell, and Basil Nicolaenko — *Mathematical Studies*, **61** (1982).

- **Order in Chaos** 5/24-28/82; David Campbell, Harvey Rose, Al Scott, Mitchell Feigenbaum — *Physica* **7D** (1983).

- **Fronts, Interfaces and Patterns** 5/2-5/83; Paul Channel, Larry Campbell, and Alan Bishop — *Physica* **12D** (1984).

- **Transport and Propagation in Nonlinear Systems** 5/20-25/84; Gary Doolen, Alwyn Scott, and Alan Bishop — *Journal of Statistical Physics* **39** (1985).

- **Evolution, Games and Learning** 5/21-25/85; Doyne Farmer, Alan Lapedes, Norman Packard, and Burt Wendroff — *Physica* **22D** (1986).

- **Nonlinearity in Condensed Matter** 5/5-9/86; Alan Bishop, David Campbell, Peter Kumar, Steven Trullinger — *Springer-Verlag Solid State Sciences* **69** (1987).

- **Nonlinearity in Medicine and Biology** 5/18-23/87; Alan Perelson, Byron Goldstein, Micah Dembo, and John Jacquez — *North-Holland Mathematical Biosciences* **90** (1988).

- **Advances in Fluid Turbulence** 5/16-20/88; Gary Doolen, Robert Ecke, Darryl Holm, and Victor Steinberg — *Physica* **37D** (1989).

- **Models of Emergent Computation** 5/22-26/89; Stephanie Forrest — *Physica* **42D** (1990).

- **Nonlinear Science: The Next Decade** 5/21-25/90; David Campbell, Robert Ecke, and J. Mac Hyman — *Physica* **51D** (1991).

- **Experimental Mathematics: Computational Issues in Nonlinear Science** 5/20-24/91; J. Mac Hyman, David Campbell, and David Brown — *Physica* **D** (1992).

- **Nonlinearity in Materials Science** 5/18-22/92; Alan Bishop, Robert

Ecke, and James Gubernatis — *Physica* **D** (1993).

- **Modeling the Forces of Nature** 5/17-21/93;
- **Quantum Complexity in Mesoscopic Systems** 5/16-20/94; Alan Bishop, Robert E. Ecke, and Ronnie Mainieri — *Physica* **83D** (1995).
- **Nonlinear Phenomena in Ocean Dynamics** 5/15-19/95;
- **Landscape Paradigms in Physics and Biology: Concepts, Structures & Dynamics** 5/13-17/96; Hans Frauenfelder, Alan Bishop, Angel Garcia, Alan Perelson, Peter Schuster, David Sherrington, and Pieter J. Swart — *Physica* **D 107** (1997).
- **Nonlinear Waves and Solitons in Physical Systems** 5/12-16/97;

Scientific and Administrative Staff

Since its inception in 1980, the CNLS has under the directorshiop of: Alwyn Scott, David Campbell, Donald Cohen and Hans Frauenfelder. Begining in 1987 there has also been the position of Deputy Director and it has been held by: Gary Doolen, Charlie Doering, and Shiyi Chen. Several Laboratory staff members have held the acting Director and acting Deputy Director while permanent candidates were found. In addition, Y. C. Lee was the CNLS Senior Scientist from 1986 to 1991. Below we list CNLS personnel since 1980.

Scientific Staff

- **David Campbell** Director, 1985–1992.
- **Shiyi Chen** Deputy Director, 1997–present.
- **Donald Cohen** Director, 1994–1995.
- **Charlie Doering** Deputy Director, 1995–1996.
- **Gary Doolen** Deputy Director 1987–1992; Acting Director, 1990–1994.
- **Robert Ecke** Acting Deputy Director, 1991-1993.
- **Hans Frauenfelder** Director, 1995–present.
- **Erica Jen** Acting Deputy Director, 1993-1994.
- **Y. C. Lee** Senior Scientist 1986–1991.
- **Ronnie Mainieri** Acting Deputy Director, 1997.
- **Alwyn Scott** Director, 1981–1984.

Administrative Staff

- **Janet Gerwin** Administrative Assistant, 1980–1981.
- **Mary Francis Gomez** Office Manager, 1981–1996.
- **Marian Martinez** Administrative Assistant, 1982–1990.
- **Kathy Salgado** Administrative Assistant, 1983–1985.
- **Dorothy Garcia** Administrative Assistant, 1985–present.
- **Valerie Ortiz** Administrative Assistant, 1985–1988.
- **Barbara Rhodes** Administrative Assistant, 1989–present.
- **Susan Spach** Administrative Assistant, 1989–1994.
- **Janet Pacheco-Morton** Administrative Assistant, 1995–1997.

- **Rose Vigil** Administrative Assistant, 1995-1997.
- **Kathy Salgado** Office Manager, 1997–present.
- **Catherine Miller** Administrative Assistant, 1997.
- **Roderick Garcia** Administrative Assistant, 1997–present.
- **Peter Ford** Systems Administrator, 1987–1990.
- **Susan Coghlan** Sytems Administrator, 1991–1995.
- **David Neal** Sytems Administrator, 1995–present.

Internal Sabbaticals

Beginning in 1985 a number of individuals have taken internal sabbaticals at the Center for Nonlinear Studies. They are Chris Barnes (1987), Roger Jones (1989), and Bill Mead (1990), all of the X-5 group at the Laboratory. They were each paid by their Division to spend one year working in CNLS and learning some aspect of nonlinear science. They concentrated on adaptive dynamical systems and neural networks, working closely with the CNLS Senior Scientist, Y. C. Lee.

External Advisory Committee

The CNLS receives annual advice and review by an external panel of distinguished members of the nonlinear science community. Over the years the External Advisory Committee has been instrumental in helping guide CNLS and acting both as a critic and an advocate. Its members have included:

- **Mark Kac** Rockefeller University.
- **Isadore Singer** Univ. California, Berkeley and MIT.
- **Roger Dashen** Univ. of California, San Diego.
- **Martin Kruskal** Princeton University.
- **Ruterford Aris** University of Minnesota.
- **J. Robert Schrieffer** University of California, Santa Barbara.
- **Alwyn Scott** Univ. of Arizona.
- **Guenter Ahlers** University of California, Santa Barbara, 1987–Present.
- **Mitchell Feigenbaum** Rockefeller University.
- **Peter Lax** Courant Institute.

Past pstdoctoral fellows

We have listed CNLS' postdoctoral fellows and their positions in 1998. Of the 104 postdoctoral fellows, 26 have remained at the Laboratory as staff members.

ALEXANDER	Frank	Boston University
AN	Zhi-Gang	NYNEX Science & Technology
ANDERSON	Russell	University of California Berkeley
ATLAS	Susan	University of New Mexico
BLUMENFELD	Raphael	Molecular Simulatries Inc.
BONCA	Janez	J. Stefan Instiutte
BROWN	David L.	CIC-19 Staff Member
BRUNO	Bill	T-10 Staff Member
BRYNGELSON	Joe	
BUDZINSKI	John	DX-3 Staff Member
BURGESS	Don	
BURTSEV	Sergey	Corning Incorporated
CAMASSA	Roberto	T-7 Staff Member
CHEN	Hudong	Exa Corporation
CHEN	Shi-yi	CNLS Deputy Center Leader
CHOI	Wooyoung	T-7 Staff Member
DAVID	Daniel	
DILTS	Gary	X-HM Staff Member
DOERING	Charles	University of Michigan
DORIA	Mauro	Pontificia Universidade Catolica
EUBANK	Stephen	TSA-DO-SA Staff Member
EYKHOLT	Richard	Colorado State University
FARMER	James Doyne	The Prediction Company
FONTANA	Walter	Santa Fe Institute
FORREST	Stephanie	University of New Mexico
GABLE	Carl	ESS-5 Staff Member
GAMMEL	Tinka	T-1 Staff Member

GAO	Xiaoming	Varian Corporation
GLASSER	Robert	
GROSSMAN	Tal	Deceased
GUTOWITZ	Howard	ESPCI
HAGBERG	Aric	T-7 Staff Member
HE	Xiaoyi	T-13 Limited Staff
HOCHBERG	Judy	CIC-3 Staff Member
HOU	Ming-Kang	
HUNKE	Elizabeth	T-3 Staff Member
HUYNEN	Martijn	EMBL
JANSSEN	Robert D.	X-NH Staff Member
JEN	Erica	Santa Fe Instiute
JOHNSTON	C.	
JONES	Don	Arizona State University
KAWASHIMA	Naoki	Toho University Japan
KE	Liu	Neural Network Adaptive Control
KEVREKEDIS	Ioannis	Princenton University
KHAMAYSEH	Ahmed X-CM	Staff Member
KIMURA	Yoshifumu	Nagoya University
KLUGER	Yuval	Lawrence Berkeley National Laboratory
KNAPP	Robert	
KOVACIC	Gregor	Rensselaer Polytechnic Institute
LANGTON	Chris	Santa Fe Institute
LAYNE	Scott	
Li	Jia	University of Alabama
LI	Ning	MST-10 Staff Member
LIHONG	Wang	TRW, California
LIN	Hai-Qing	The Chinese University of Hong Kong
LIU	Yuanming	JPL
LLOYD	Seth	MIT
LOH	Eugene	SUN Microsystems
LOMDAHL	Peter	T-11 Staff Member
LONGTIN	Andre	University of Ottowa
LU	Liang	Wave Propagation
LUCE	Benjamin	T-7 Staff Member
LUO	Yong	CIC-19 Staff Member
MAINIERI	Ronnie	T-13 taff Member

MARIANER	Shlomo	University of Minnesota
MARTIN	Thierry	Universite d'Aix Marseille II
MAYER-KRESS	Gottfried	Center for Complex Systems Research
MAZOR	Avi	Rafael Group 19, Israel
MAZUMDAR	Sumitendra	University of Arizona
MCKINSTRIE	Collin	
MCNAMARA	Guy X-CI	Staff Member
MEHR-GROSSMAN		Princeton University
MILLONAS	Mark	University of Chicago
MUKERJEE	P	
MUTO	Virginia	University del Pais Vasco Spain
NADIGA	Balasubramanya	X-HM Staff Member
OLSON	Jeffrey	
ORON	Alexander	Technion
OTTO	James	University of New Mexico
PEARSON	John X-CM	Staff Member
PETERSSON	Nils Anders	Chalmers University of Technology
QIAN	Songnian	
RANDALL	Ellen	CIC-19 Staff Member
RASMUSSEN	Steen	EES-5 Staff Member
REIDER	Marc	IBM
RIGHTLEY	Maria	X-NH Staff Member
RUSSELL	David	University of Colorado
SATIJA	Indu	George Mason University
SOBEHART	Jorge	Center for Adaptive Complex Systems
SOMSKY	William	University of Washington
STANLEY	Ann	T-7 Consultant
STEWART	Cheryl	New York University
SULLIVAN	Tim	Kenyon College
THEILER	James	NIS-2 Staff Member
TRATNIK	Michael	
TUFILLARO	Nicholas	Hewlett Packard Company
UEDA	Tetsuji	University of North Carolina
WAGNER	Barbara	Universtiy of Arizona
WANG	Xidi	Citi Corporation
WOLPERT	David	NASA Ames
XIONG	Shanji	Center for Adaptive Complex Systems
YOUNG	Karl	NASA/AMES Research Center
ZHANG	Shiwei	College of Willaim and Mary
ZHARNITSKY	Vadim	Brown Univeristy
ZHONG	Fang	Duke University

Computing at CNLS

CNLS tries to provide adequate computing facilities to its postdoctoral fellows and visitors. It keeps a systems administrator on staff that installs new equipment, maintains the network, handles the backups, and helps users in using the system and installing new software. In the current arrangement, each postdoctoral fellow is given a dual Pentium processor computer with 192 megabytes of memory running the Linux version of the Unix operating system. These machines are interconnected by a 100 megabit/second Ethernet. The files are kept on a file-server that provides some redundancy (a RAID).

Besides the software that is provided with Linux, CNLS has purchased licenses to several commercial packages. It has installed Mathematica, Maple, and Axiom for symbolic manipulation, MATLAB for numerical linear algebra, and IDL for visualization. Some of the computers have specialized compilers. It also provides a NAG mathematical library on the Linux machines.

Aside from the Pentium-based computers, CNLS has a few computers from Silicon Graphics and Sun Microsystems. These machines are needed for the execution of commercial software that does not exist for the Linux operating system. These are considered computing-servers. One of them is a four-processor shared memory machine from Silicon Graphics, an Origin 200. It has 256 megabytes of memory and each processor has a dedicated floating point unit.

There are also two Apple Macintosh computers used for graphical design. They each have a copy of Adobe Photoshop and Adobe Illustrator.

The challenge facing CNLS in the area of computing is how should it proceed? In the 1980's, many of the visitors of CNLS would come to use its computing facilities. It was then simple to provide access to other Laboratory supercomputers. Today, with the advent of inexpensive computing power, the computing facilities of CNLS do not differ in degree from those available at a university or in industry.

These are a few questions that the Executive Committee has been faced with: Should CNLS have a message-passing parallel machine? Should it provide a machine for code development that would then be executed on the large Laboratory supercomputers? Should it concentrate on having in-house experts for some software packages? Should it invest in a nonlinear editing facility for the production of scientific visualization movies? Is there a way to optimize our investment so that computers do not have to be replaced every two years? Where is scientific computing headed?